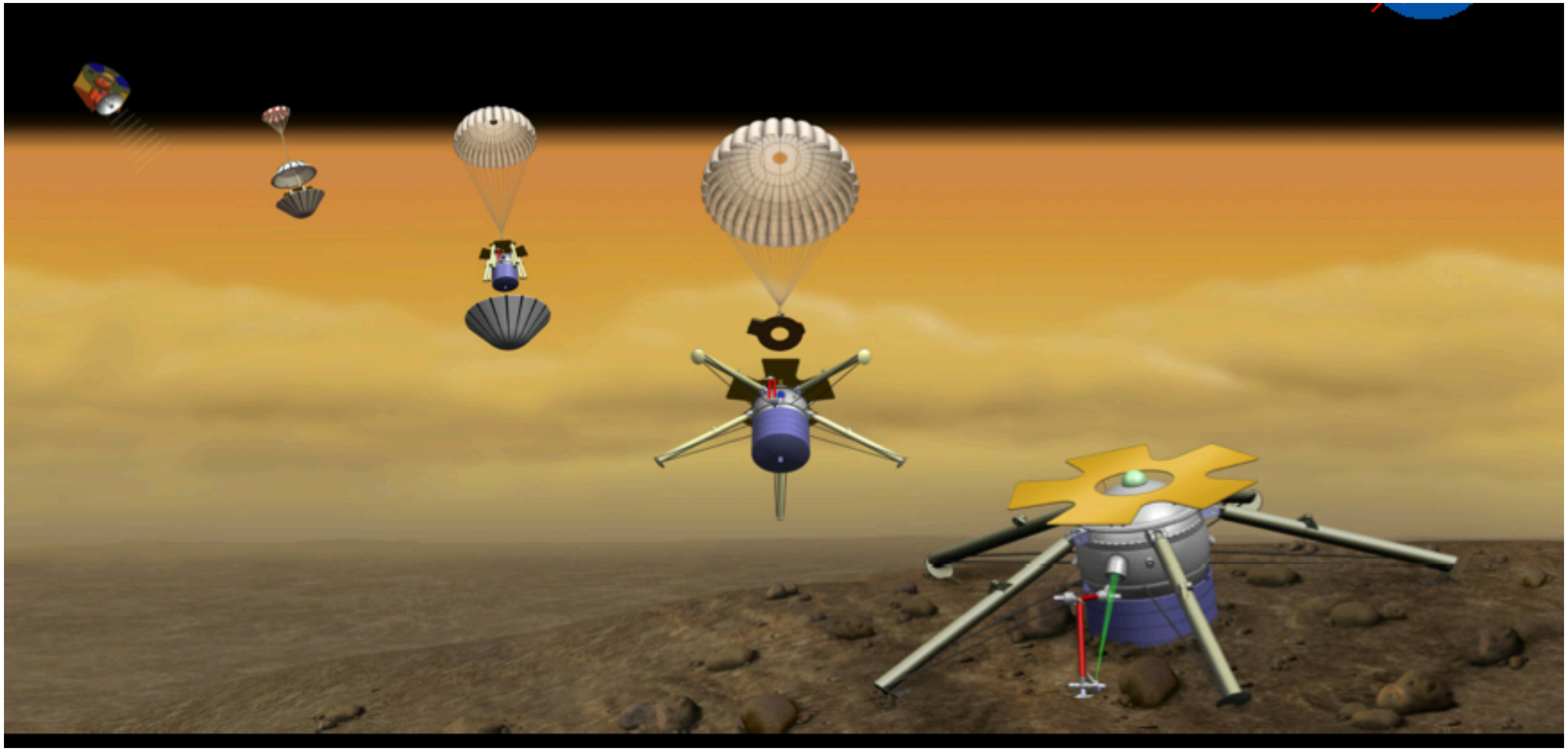
Initial Development of a Venus Entry System for a Surface and Atmosphere Geochemical Explorer

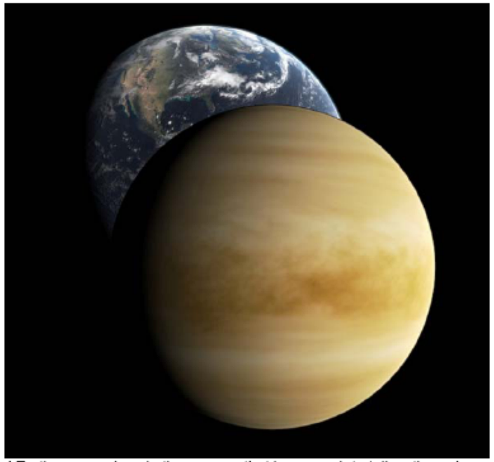


Anita Sengupta, Jet Propulsion Laboratory, California Institute of Technology
Rob Maddock, Juan Cruz, NASA Langley Research Center
Dinesh Prabhu, Paul Wercinski, NASA Ames Research Center

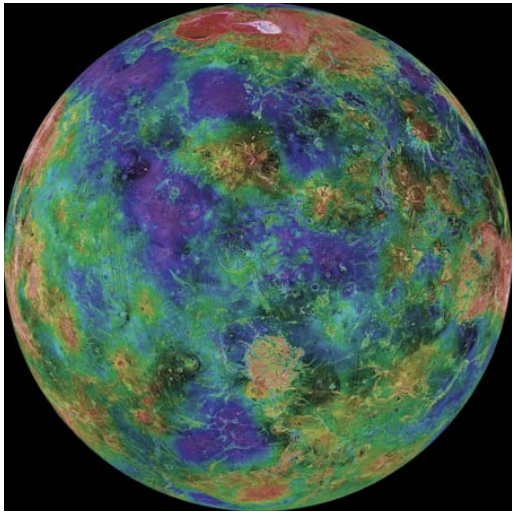
Venus Exploration Motivation

- Venus is a critical science target
  - Terrestrial planet comparative planetology
  - Similarity to Earth
  - Climate evolution
  - Volcanic Activity
  - Limited Venus science over past 50 years

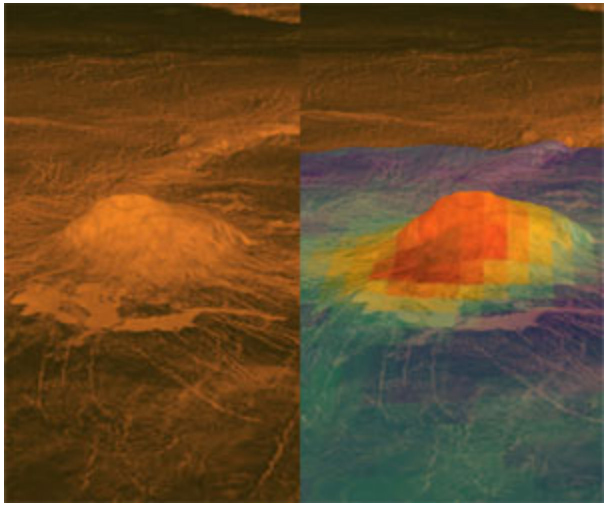
- NASA New Frontier, Discovery, and Venus Flagship Mission are under concept development



Earth and Venus



Venus Topography



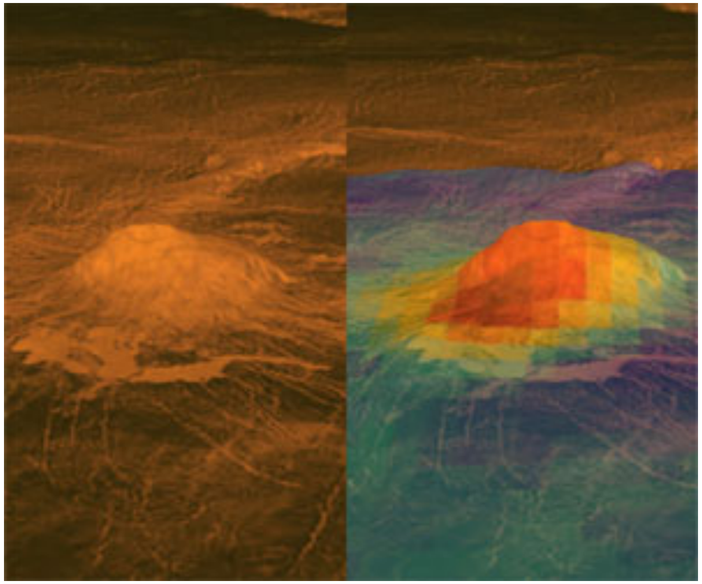
Volcanic Activity

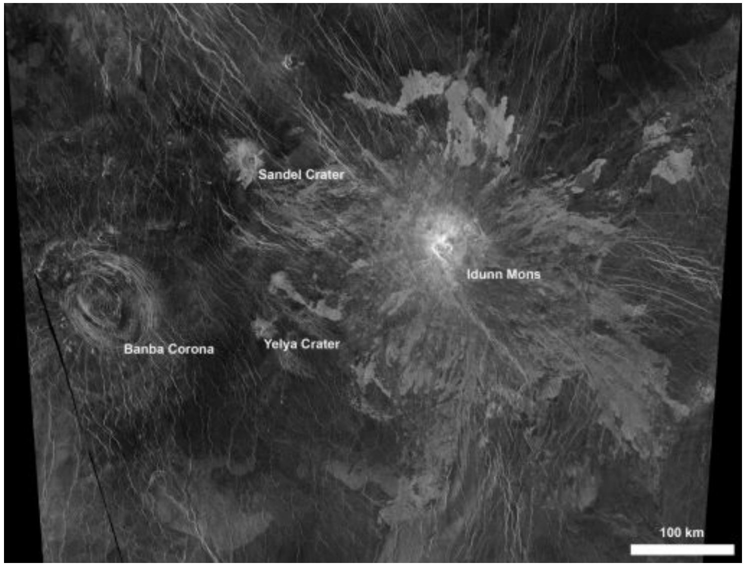
•Images courtesy NASA and ESA

Venus Exploration Motivation

- Thermal emission measurements from the Venus express probe indicate recent volcanic activity on the sfc (<2 million years ago)
  - Even more recent suggests within the past hundreds of year!
- Implications to climate change theories
- Explains absence of craters as a method of resurfacing
- More insight into terrestrial planet formation

Surface Mission is Key to Understanding this New Finding!

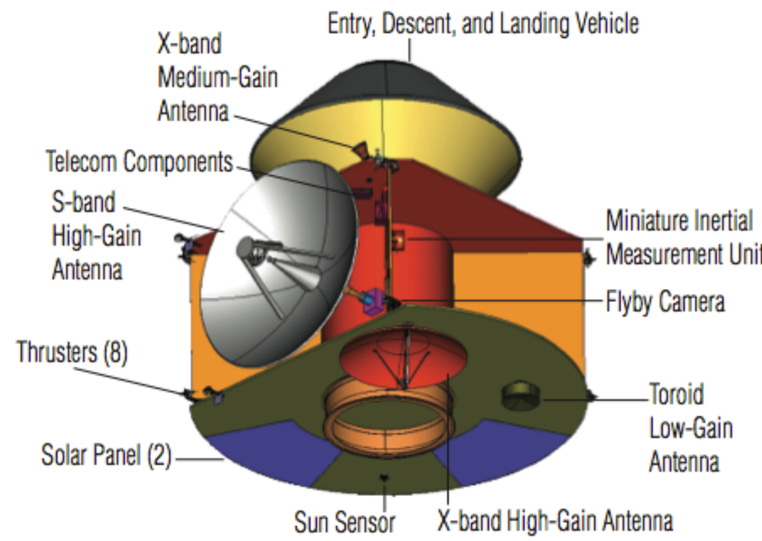


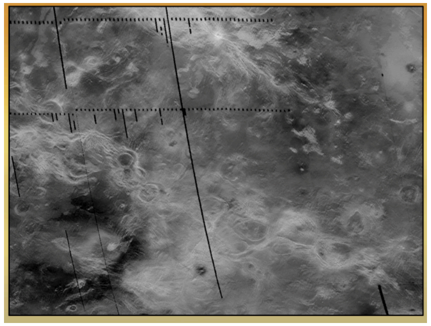


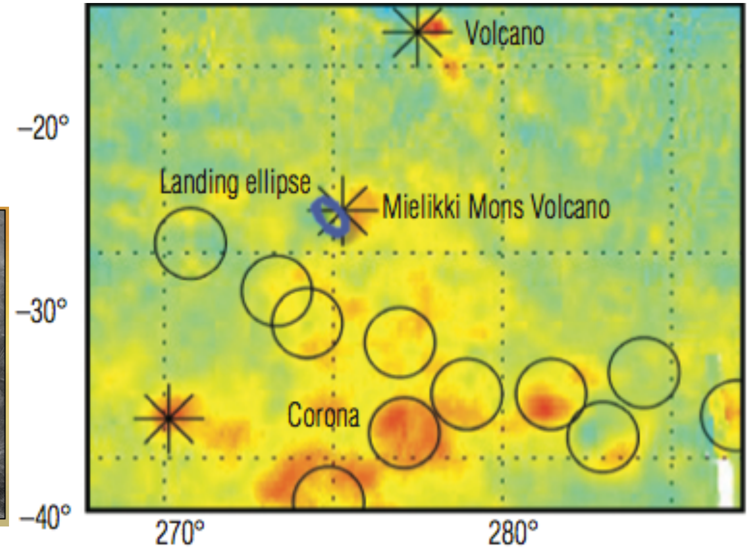
•Images courtesy NASA and ESA

SAGE Mission Overview

- Science Goals
  - Why is Venus so Different from Earth?
  - Was Venus once like Earth
  - Does Venus represent Earth fate
- Mission design
  - Carrier S/C with entry probe and lander element
  - S-band Science data transmission to carrier
  - X-band DTE form the carrier
  - 136 day cruise, 1 hour atmospheric descent, 3 hour surface life
- Landing Site
  - Flank of one of Venus's many volcanoes.
  - High-emissivity regions (red) are interpreted to be areas where lava flows are relatively recent.
  - Area free of surface hazards and steep terrain
  - Rock distribution and surface hardness similar to Venera landing sites
- Science
  - Atmospheric Dynamics
  - Atmospheric Composition
  - Surface Geology and Weathering
  - Surface Composition and Mineralogy







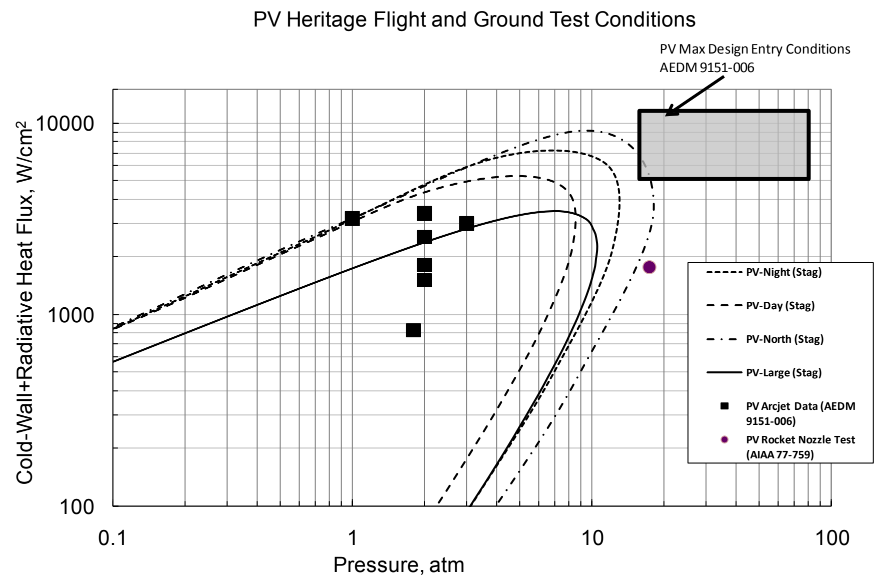
B. Bienstock and G. Burdick, The SAGE New Frontiers Mission to Venus," IPPW 7, June 15th 2010.

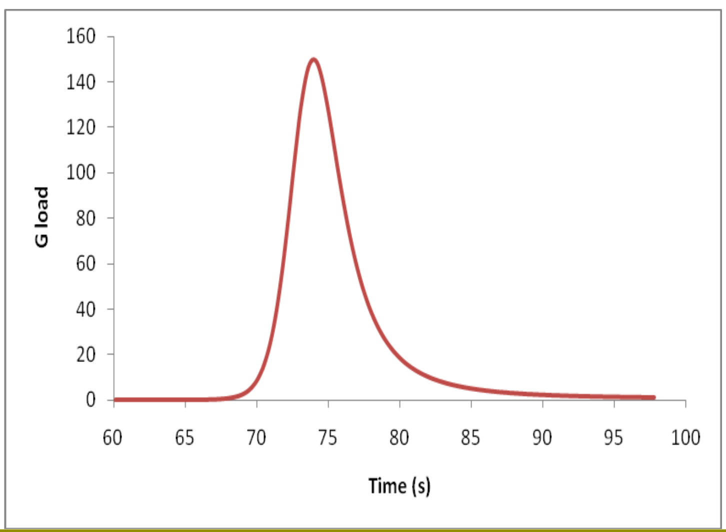
Instrument Suite

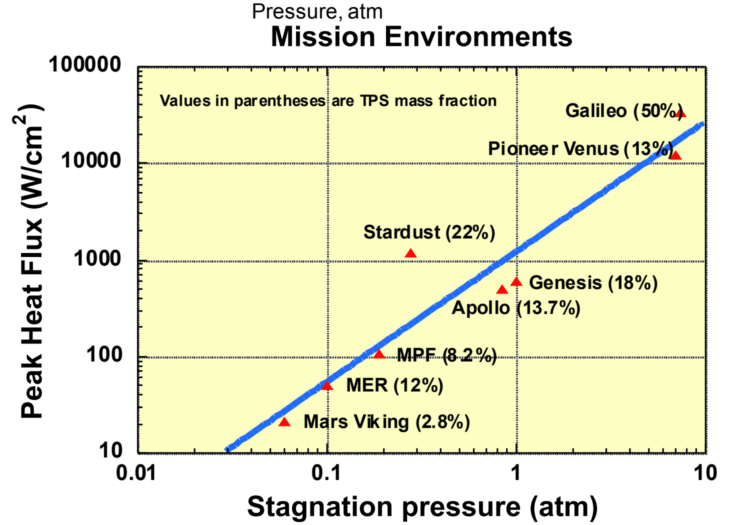
Objective/Instrument	Measurements	Provider
Atmospheric Dynamics		
• Flyby Camera (FBC)	• Ultraviolet and near-infrared imaging for entry context and cloud dynamics	• Space Research Institute of the Russian Academy of Sciences
• Atmospheric Structure Investigation (ASI)	• Temperature, pressure, dynamics, and wind speed	• NASA Ames Research Center
Atmospheric Composition		
• Tunable Laser Spectrometer (TLS)	• Stable isotope ratios	• Jet Propulsion Laboratory, California Institute of Technology
• Neutral Mass Spectrometer (NMS)	• Measure major, trace, and noble gas species	• NASA Goddard Space Flight Center
Surface Geology and Weathering		
• Descent and Panoramic Cameras (DPC)	• Descent and surface imaging	• Malin Space Science Systems
• Microscopic Camera	• Imaging of Raman/LIBS site	• Malin Space Science Systems
Surface Composition and Mineralogy		
• Neutron-Activated Gamma-Ray Spectrometer (NAGRS)	• Major, minor, and trace surface and subsurface elements	• Space Research Institute of the Russian Academy of Sciences
• Raman and Laser-Induced Breakdown Spectroscopy (LIBS)	• Surface and subsurface minerals and elements	• Los Alamos National Laboratory

EDL Technology Challenges

- Driving Requirements
  - Entry Load (100 to 200 g's)
  - Entry Heating (>3 kWcm^2)
  - Descent
  - Separations
  - Surface Conditions
    - Temp, Pressure rocks, hardness
    - Short lifetime on SFC (science & telecom strategy)





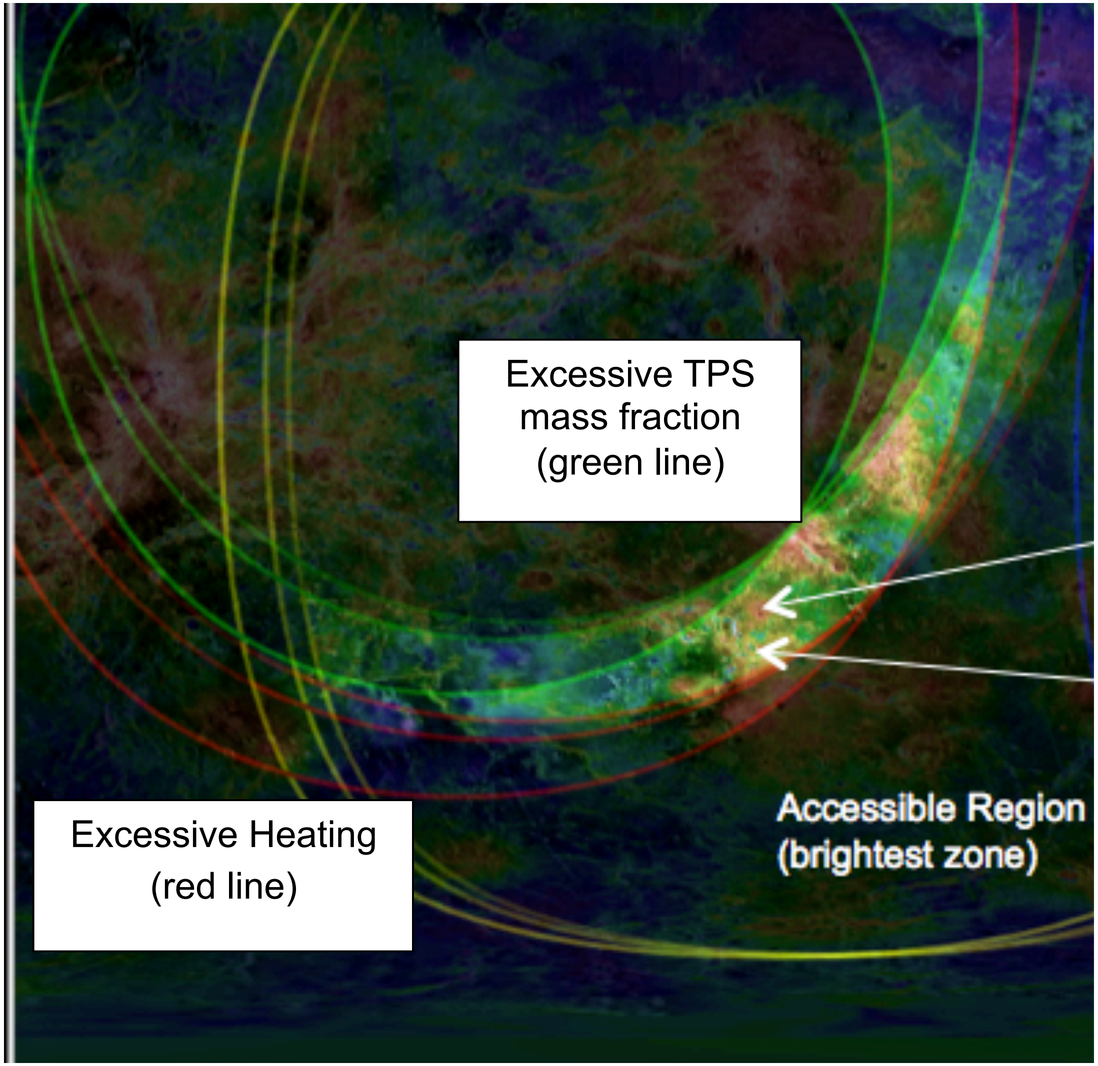


Laub, Venkatapathy et al.

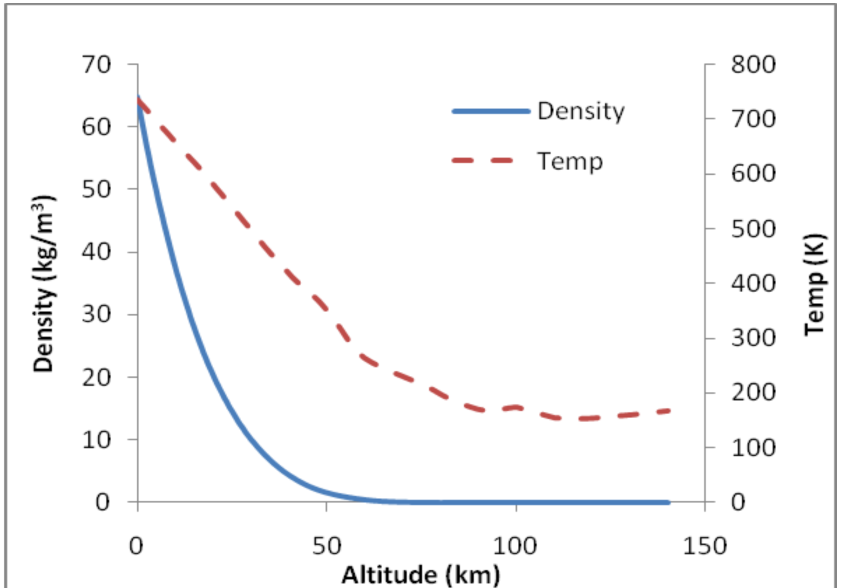
A. Sengupta et al., "Challenges of a Venus Entry Mission, IEEE, March 2011

EDL Considerations: Surface Accessibility

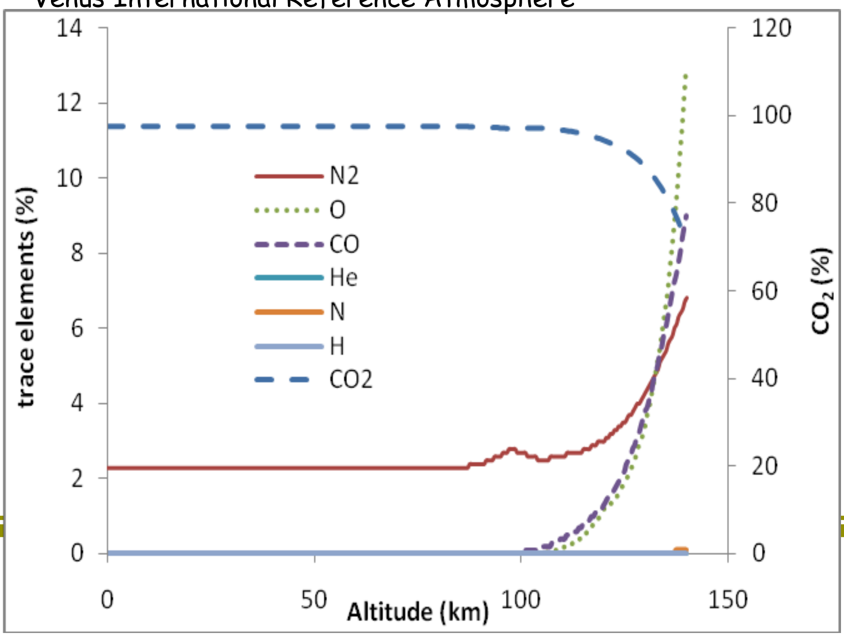
- Surface accessibility is dictated by EDL constraints
  - Too steep drives peak heating and g's
  - Too shallow drives up TPS Mass Fraction and skip-out potential
- EDL technology further constrains
  - Testing considerations
- Systems level trade
  - Landed Mass
  - Science Driven Landing site
  - Carrier spacecraft capability

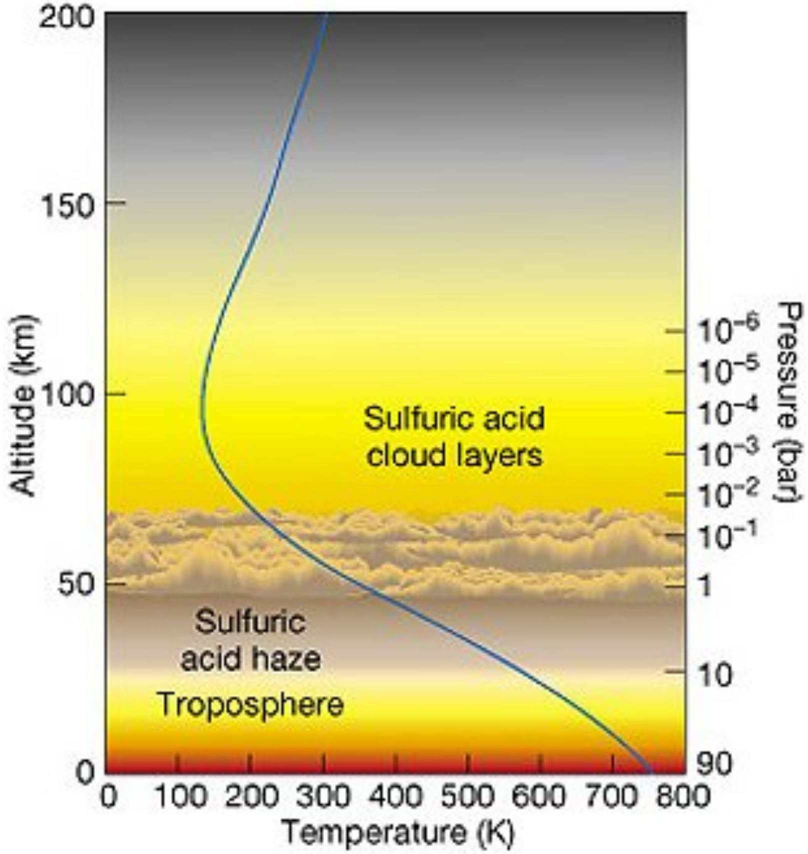


EDL Considerations: Atmosphere



Venus International Reference Atmosphere

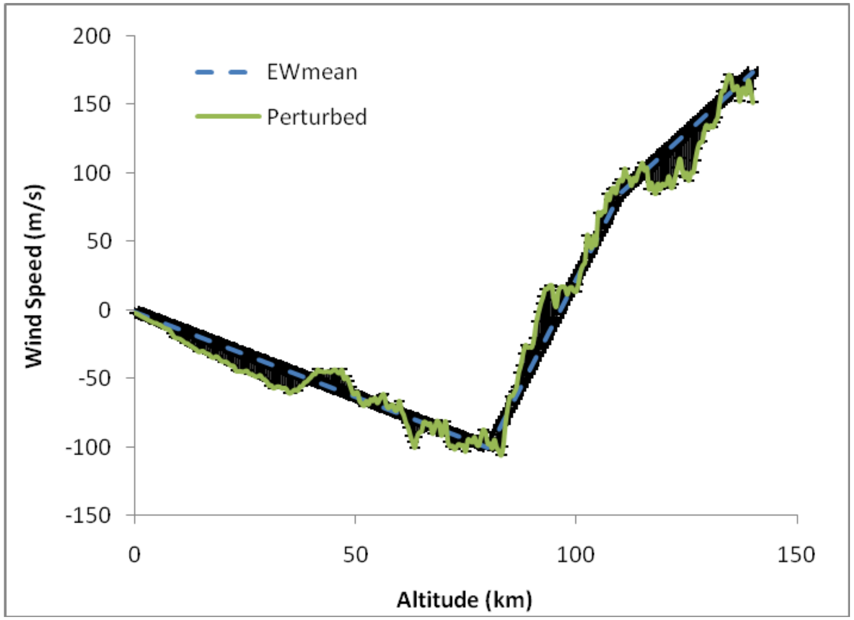


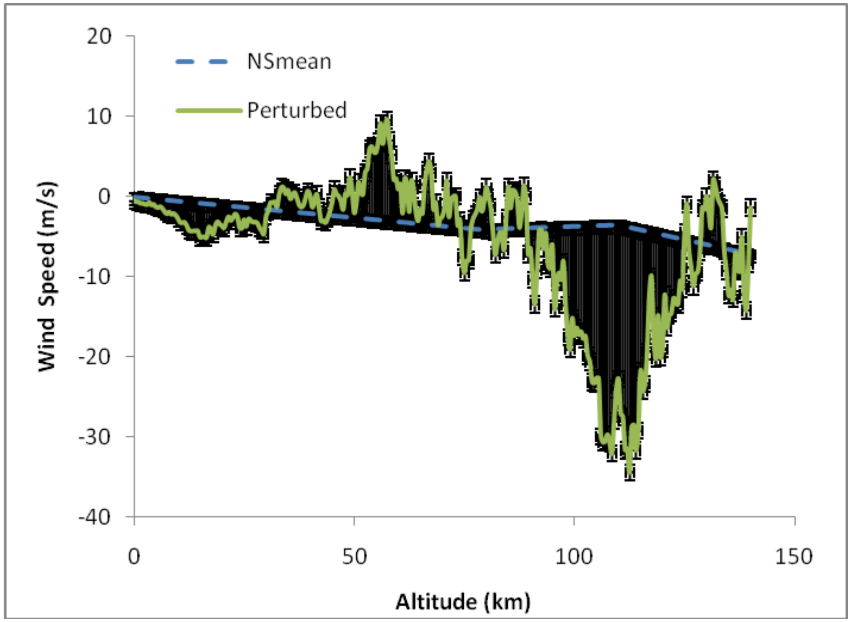


A. Sengupta et al., "Challenges of a Venus Entry Mission, IEEE, March 2011

EDL Considerations: Winds

- At the surface the wind speed is on the order of 1 to 2 m/s
- In the cloud layer winds can reach 100 m/s (at 70 km)
- Wind speed increases rapidly with altitude about 50 km.



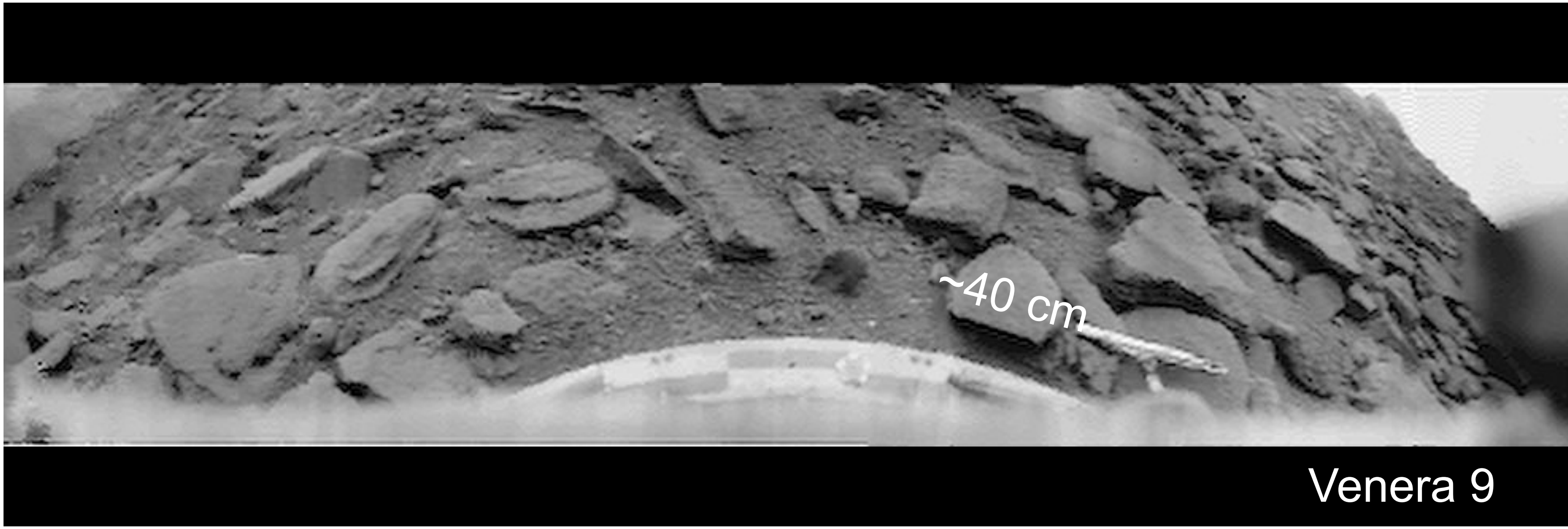


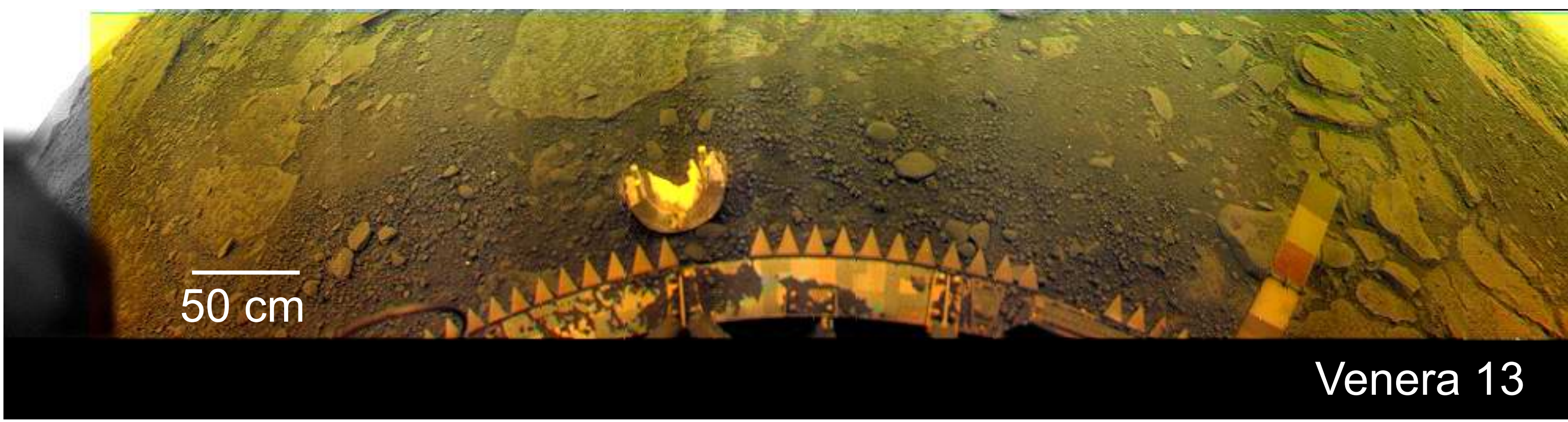
From radio occultation measurements from orbiting spacecraft (Magellan, Venera)

- Wind model incorporated into POST simulations
- Wind included in landed stability (1 m/s winds at surface)

A. Sengupta et al., "Challenges of a Venus Entry Mission, IEEE, March 2011

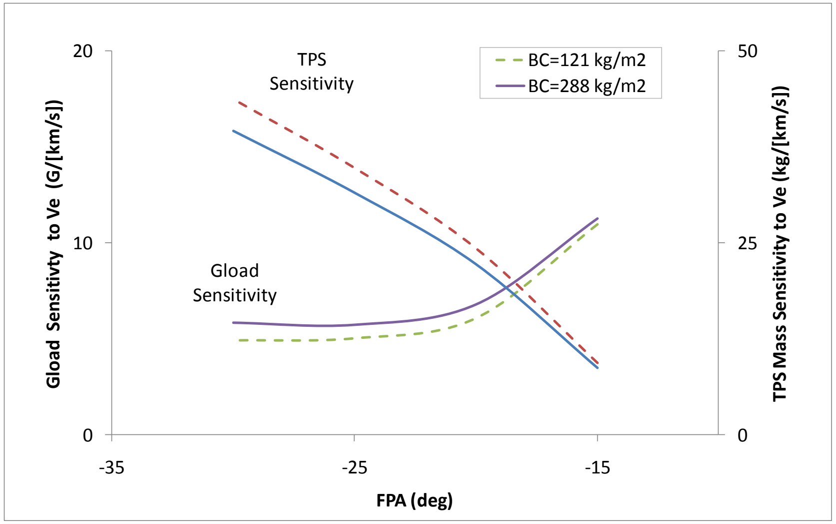
EDL Considerations: Surface Features

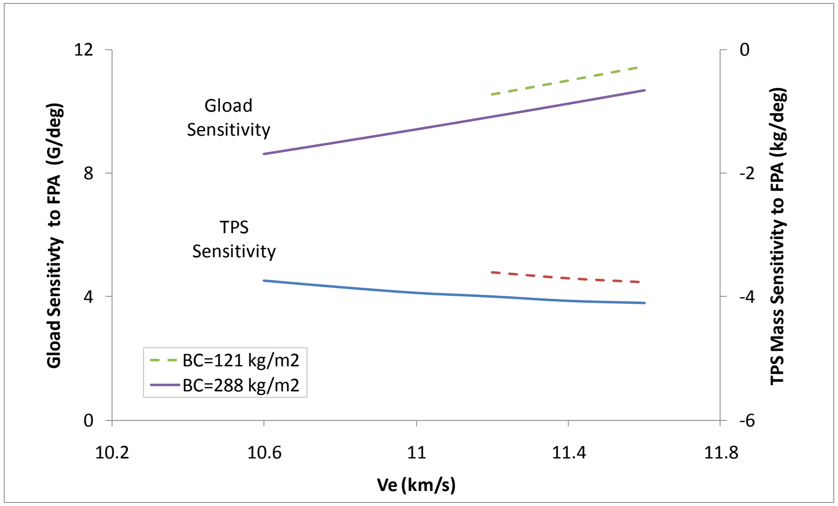




Entry Sensitivities: G-load and TPS Mass

- G-load sensitivity to V_e
  - Most dramatic effect at FPA< -20 deg
  - Minor dependence on BC
  - Reducing V_e has minimal G-load reduction
- G-load sensitivity to FPA
  - Minor increase with V_e
  - Minor dependence on BC
  - Shallowing FPA is best way to minimize G's
- TPS mass sensitivity to V_e
  - Most dramatic effect at steep angles
  - Minor dependence on BC
  - Reducing V_e is not best way to minimize m_{TPS}
- TPS mass sensitivity to FPA
  - Minor increase with V_e
  - Minor dependence on BC
  - Increasing FPA is best way to minimize m_{TPS}

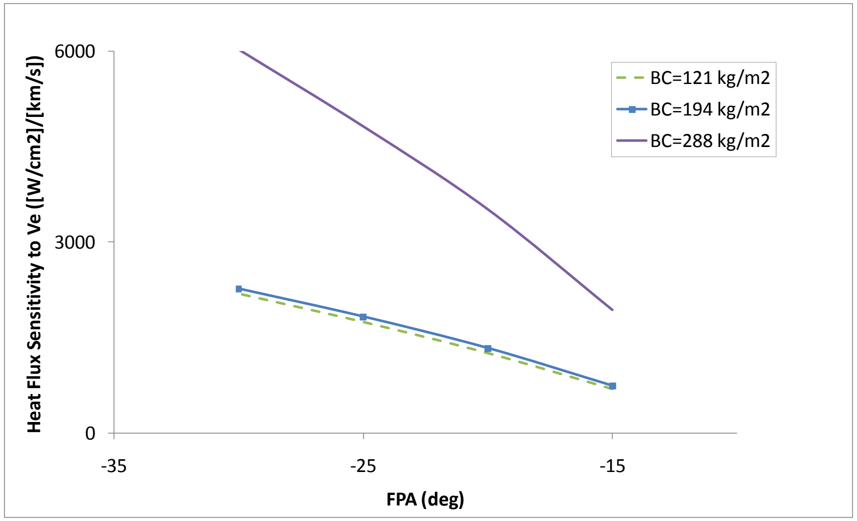


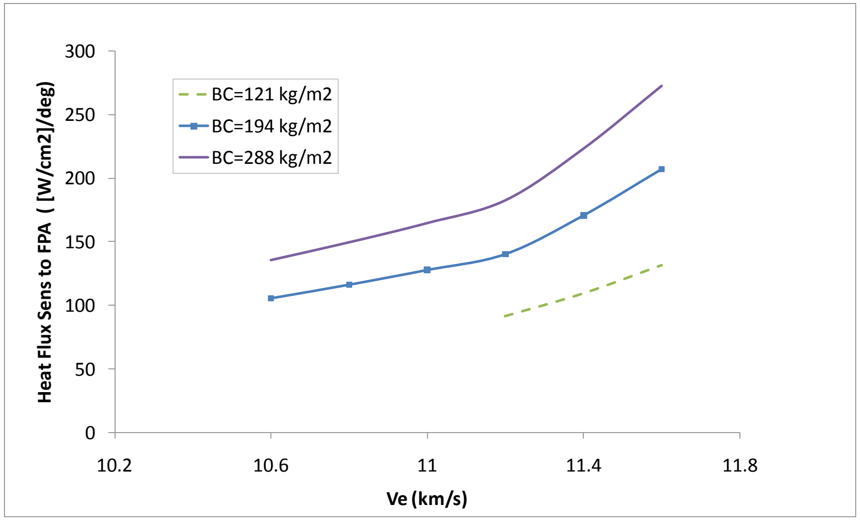


A. Sengupta et al., "Challenges of a Venus Entry Mission, IEEE, March 2011

Entry Sensitivities: Heat Flux (q)

- Heat Flux sensitivity to V_e
  - Reducing V_e is a good way to minimize q
  - Most dramatic effect at steep angles
  - Dependence on BC
  - Places more burden on the S/C prop system
- Heat Flux sensitivity to FPA
  - Shallowing FPA is good way to minimize q
  - Most dramatic effect when V_e >11.2 km/s
  - Minor dependence on BC
- G's are traded for TPS mass
- FPA reduction
  - Pro: good reduction in q and G's
  - Con: Limits landing sites, increases m_{TPS}
- V_e reduction
  - Pro: good reduction in q, modest reduction in G's and m_{TPS}
  - Con: Simply shifts mass burden on orbiter

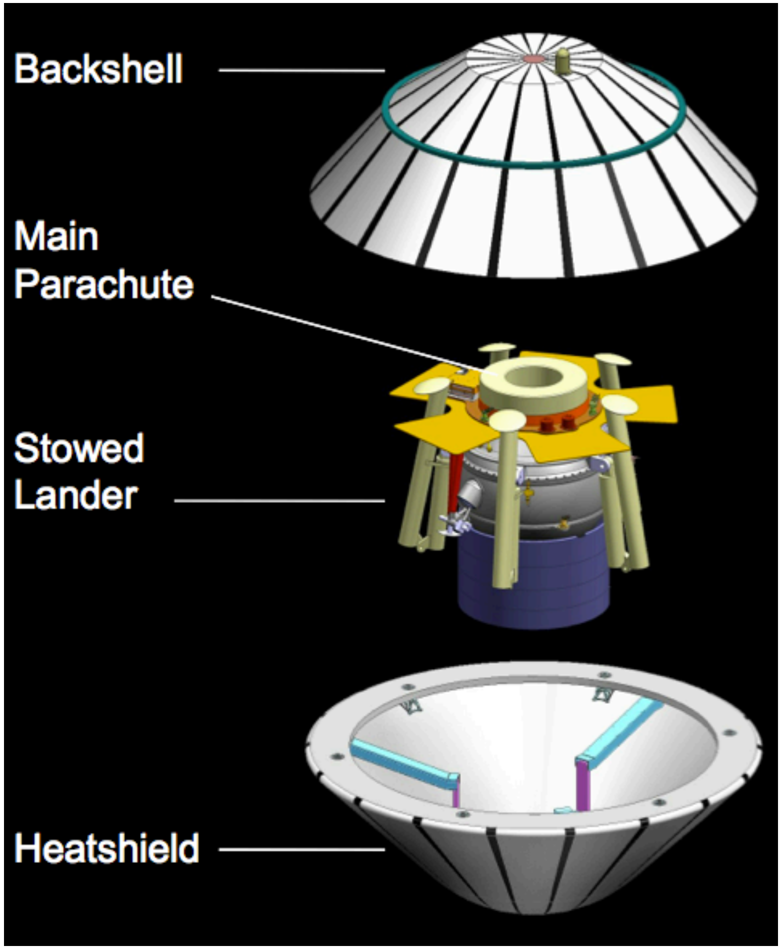




A. Sengupta et al., "Challenges of a Venus Entry Mission, IEEE, March 2011

EDLV

- Ballistic Entry in a 45 deg sphere cone aeroshell with spin (PV)
- Hypersonic to subsonic deceleration with rigid heat shield
- Subsonic parachute system to extract the lander
- <60 km to the surface the lander free-falls to the surface under a drag plate
- Landing on the surface <10 m/s
- Lander maintained at STP conditions for three hours

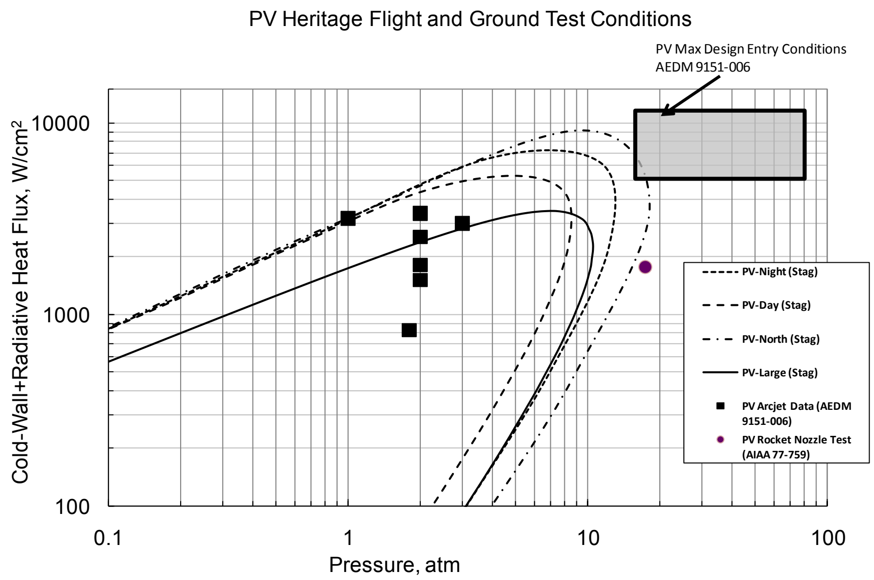


B. Bienstock and G. Burdick, The SAGE New Frontiers Mission to Venus," IPPW 7, June 15th 2010.
A. Sengupta et al., "Challenges of a Venus Entry Mission, IEEE, March 2011.

Heat Shield

- Carbon Phenolic Only TPS to withstand Venus hyperbolic entry
- DPLR and NEQAIR simulations to define peak heating with turbulent augmentation
- Combined with 6DOF POST2 simulations of descent

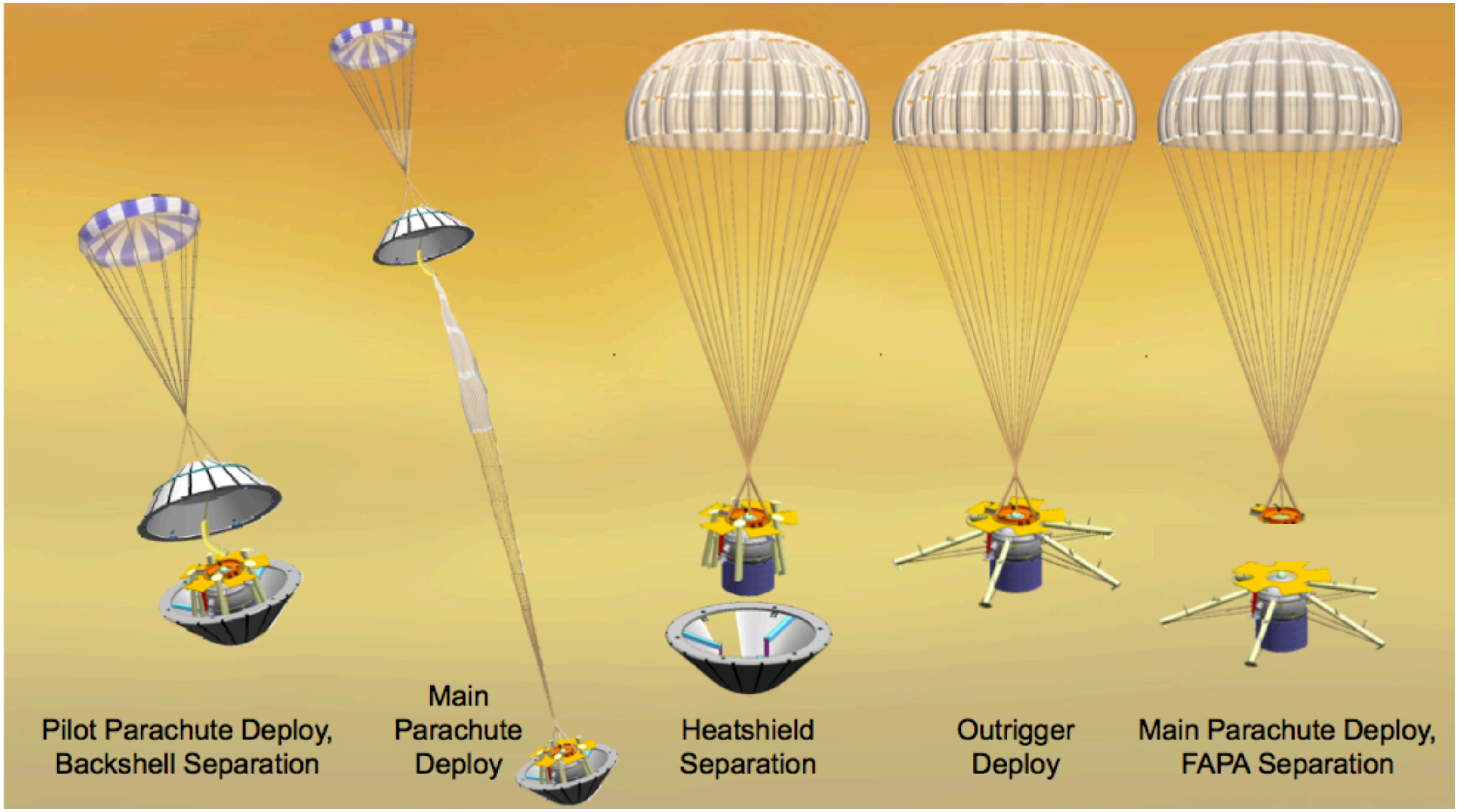
TPS	Peak Heating (W/cm2)	Peak Pressure (atm)	Density (kg/m^3)	Space Heritage
CP	100,000	<50	264.3	PV, Galileo
PICA	1500	<1	227.4	Star Dust
CC	900	<1	1890.2	Missiles
SLA 561	300	<1	1435.4	MPF, MER



A. Sengupta et al., "Challenges of a Venus Entry Mission, IEEE, March 2011

Separations

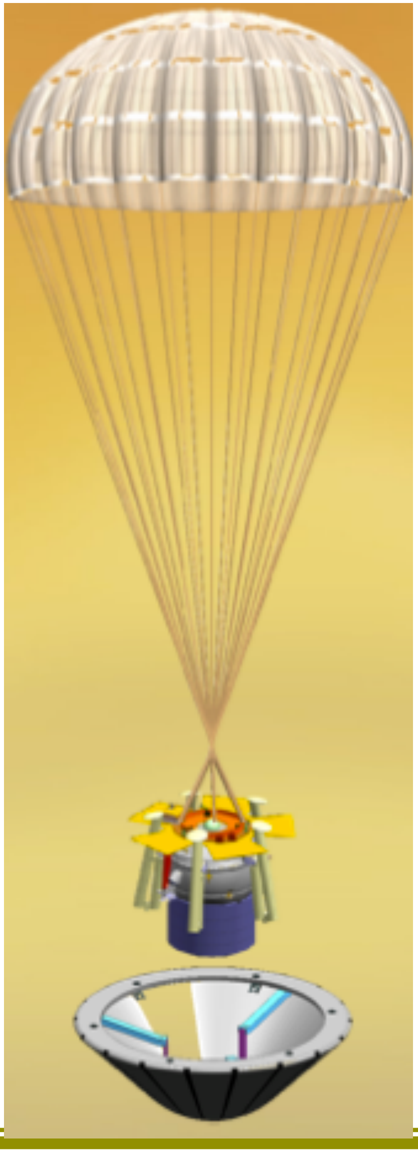
- On Venus parachute is needed for separations or staging events not deceleration



B. Bienstock and G. Burdick, The SAGE New Frontiers Mission to Venus," IPPW 7, June 15th 2010.

Parachute System

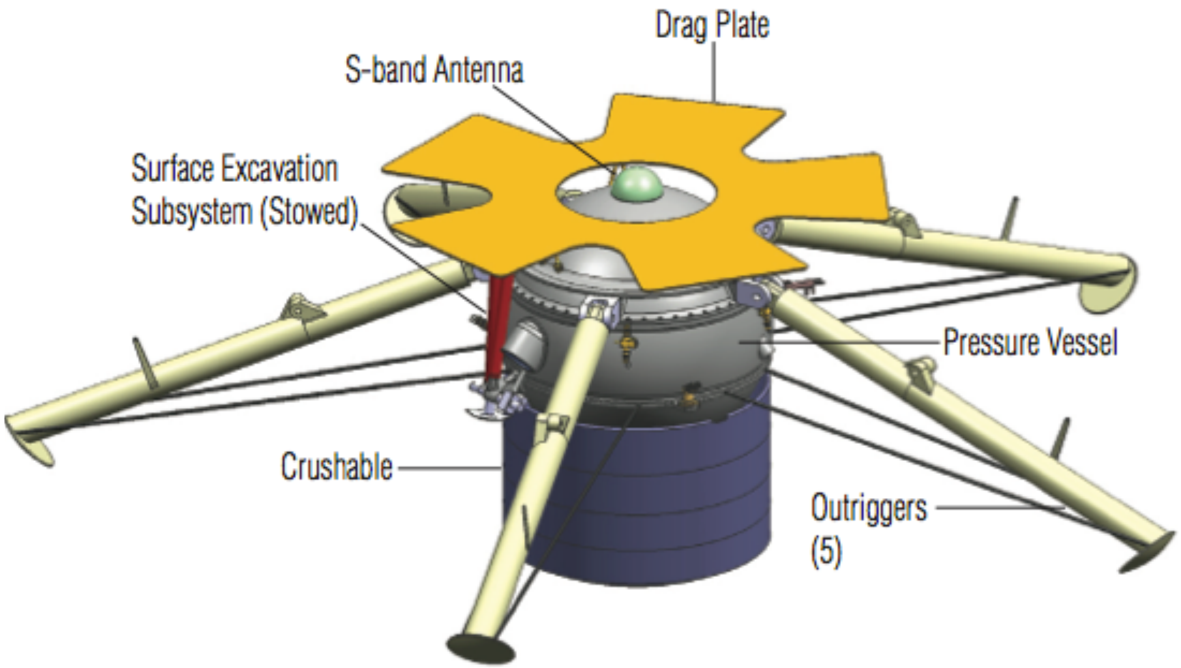
- Scaled from Pioneer-Venus parachute system
- BC separation device only
- Requirement for high stability vs. drag
- Ribbless guide surface pilot parachute for back-shell separation and main chute deploy
- Conical ribbon main chute for heat-shield separation, stabilization, mid-altitude descent
- Material selection to mitigate sulfuric acid exposure
- Subsonic deploy with similar dynamic pressure to PV

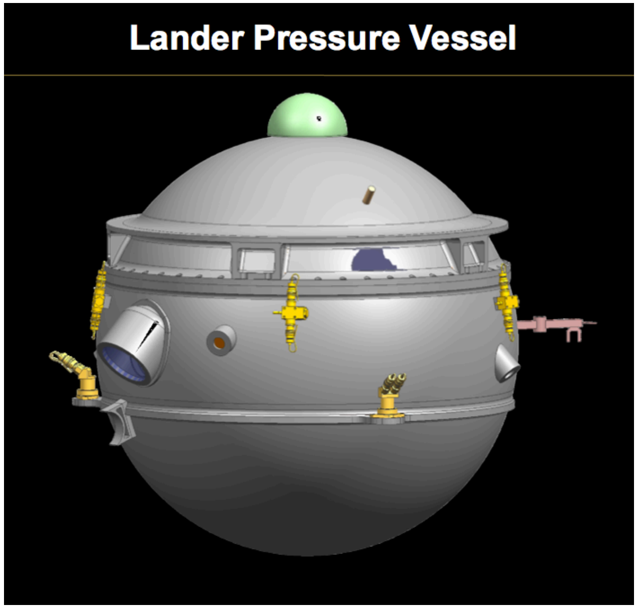


C. Kelley et al, "Parachute Development for Venus Missions," IPPW-7, June 2012.

Lander Design

- Titanium pressure vessel to accommodate thermal and pressure environment at surface houses payload and avionics
- Rigid aluminum drag plate for terminal descent deceleration
- Deployable outriggers for landed stability
- Honeycomb crushable for landing load attenuation





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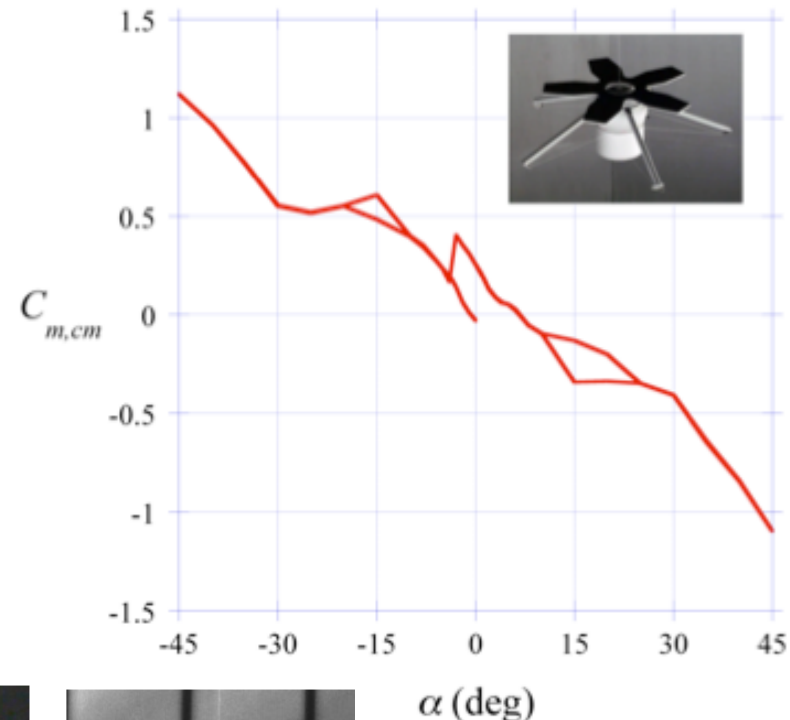
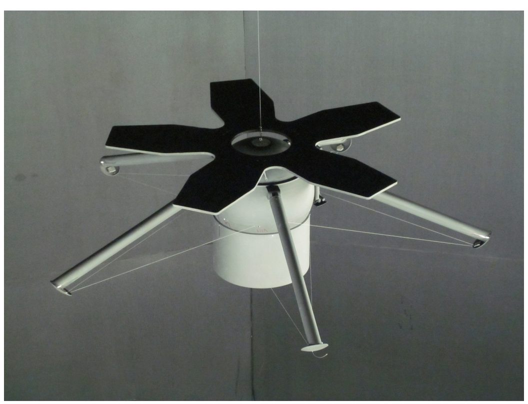
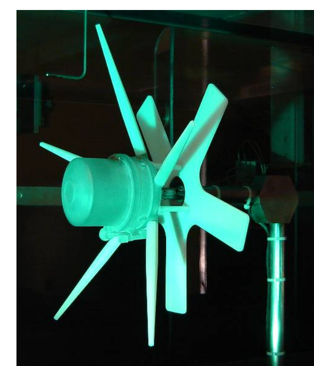
Lander Terminal Descent

- Descent stability and drag performance were required quantification with subscale wind tunnel testing
  - Subscale wind tunnel tests for static drag coefficient drag determination
  - Subscale wind tunnel test for dynamic aero coefficients / stability during terminal descent
  - Subscale water tunnel test for stability just prior to landing
  - Varied size and dihedral of drag plate to optimize drag and stability

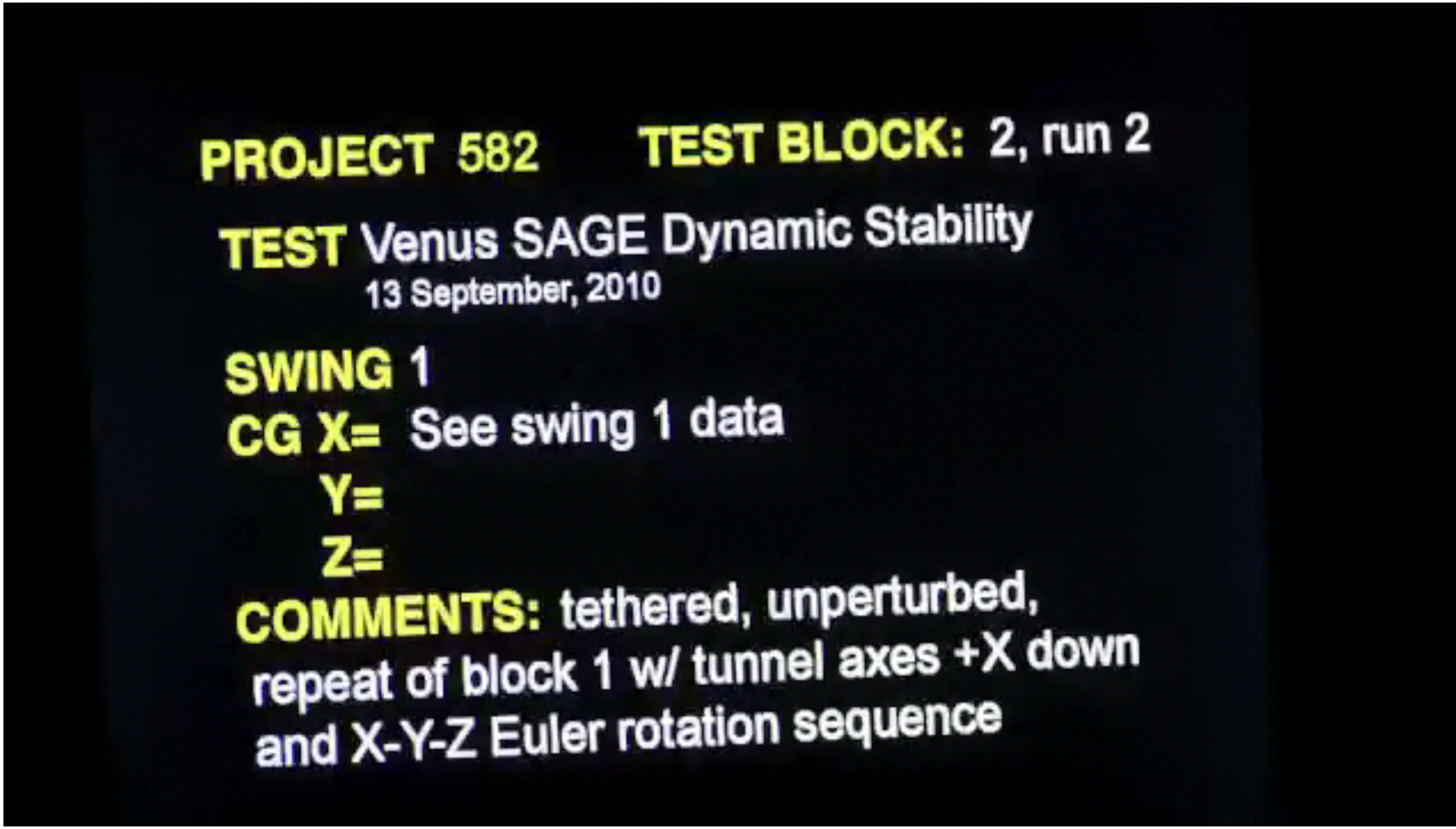






Look for future AIAA ADS paper(s) in 2013

Lander Descent in LaRC 20-ft Vertical Spin Tunnel



Conclusions

- Venus is on the horizon as a major planetary science exploration target at NASA.
- New scientific discoveries suggest the planet is geophysically active
- Entry probes and landers yield a wealth of scientific data on surface composition and geological history.
- Harsh environment of Venus and entry conditions impose several technical challenges
- Technologies already exist and have been demonstrated by NASA
- Modern entry system design process will optimize mass and performance
  - Based on the latest materials, test methods, and computational analyses